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SIMULATION TESTING OF WEAPON SYSTEMS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The testing of Army weapon systems can be significantly improved through initial use of physical simulation testing. This report discusses two simulators that are available for testing weapons and weapon systems under conditions encountered during their life cycle. The one-degree-of-freedom (1-DOF) simulator provides a variable mounting platform from which weapons can be test fired to assess the effect of the mounting conditions on operability. Sections of vehicles to which weapons are mounted are suspended from the six-degree-of-freedom (6-DOF) (cont)

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20. ABSTRACT (cont)

simulator, which imparts various vibratory types of motion to the mounted vehicle and weapons fired under these realistic conditions. The report includes a discussion of the data acquisition system which provides immediate analysis of the data obtained from simulation testing.

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INTRODUCTION

Acceptable performance of a weapon system is ultimately determined by how well it performs under combat conditions. Since the costs of fielding a system are immense, testing is performed throughout both the development and production cycles to insure that the ultimate goal of successful combat operation is met.

The testing of a weapon system consists of either costly and time-consuming field exercises or simple function-firing tests on a hard mount. To provide an effective test mechanism between these two extremes, the Army has developed a physical simulation testing capability. Physical simulation, the testing of systems under conditions duplicating those that will be encountered in the field, enables test engineers to identify and correct destructive interactions between the systems and their environment.

Background

This report describes ARRADCOM's physical simulation capability for testing small caliber weapon systems and automatic cannons. The test facility, the Ware Simulation Section of the Technical Support Directorate, is physically located at Rock Island Arsenal, and includes both one-degree-of-freedom (1-DOF) and six-degree-of-freedom (6-DOF) simulators. The 1-DOF simulator provides a variable spring rate mounting platform from which weapons are quickly tested under firing conditions to assess the interaction between the weapon and its mount. The 6-DOF simulator is capable of supporting sections of vehicles, such as helicopters or tank cupolas, and providing a realistic vibration environment while weapon systems undergo firing tests. Both these simulators are connected to an automated data acquisition and reduction system that allows analysis of test data within minutes of test completion.

Physical simulation has significant advantages over conventional weapon testing. Tests performed from either simulator provide more results per test dollar, either by reducing the requirements for costly field tests or by providing more realistic test conditions, than conventional hard stand tests. In addition to cost savings, other advantages of physical simulation include:

1. Eliminating variances in test results caused by surrounding environment, since tests are performed under controlled laboratory conditions.

2. Mounting instrumentation to measure critical weapon parameters more easily than in the field.

3. Obtaining analysis of test results immediately after completion of the test, since a data-reduction facility is in close proximity to the test ranges.

Automatic cannons (up to 30mm) firing target practice ammunition or grenade launchers (up to 40mm) firing dummy projectiles can be tested at the Ware Simulation Section. This limitation is caused by lack of ammunition storage facilities

at Rock Island Arsenal for larger caliber ammunition. All simulation testing is performed in indoor ranges to remove test variations caused by weather conditions. The 6-DOF simulator is located in a range 25-m long, while the 1-DOF simulator may be used in either a 25-m or 100-m range. All test rounds are captured by a sand impact area.

ONE-DEGREE-OF-FREEDOM SIMULATOR

The 1-DOF simulator (fig. 1) allows motion of a weapon system only along the direction of fire. The spring rate and damping of the simulator are adjustable so that the weapon-mount resonance frequency can be varied and the effect on weapon characteristics can be determined easily.

This simulator is made up of a mounting table rigidly attached to a pair of leaf springs (fig. 2). The bottom ends of the leaf springs are bolted to an outer frame that is anchored to a concrete inertia mass. Stiffness of the leaf springs is controlled by a moving assembly which is positioned by a servo-controlled hydraulic actuator. Hydraulically operated clamps also engage the leaf springs to produce the desired spring stiffness; a shift in the cantilevered length of the leaf springs changes the stiffness of the springs according to the following equation:

$$K = \frac{3EI}{L^3} \tag{1}$$

where K = spring rate (kN/m), L = length of spring (cm), E = Young's modulus (mPa), and I = moment of inertia of cross section (cm^4).

The range of spring rates for a pair of leaf springs is therefore determined by Young's modulus, the cross section, and the variable length. For the 1-DOF simulator, the length of the leaf spring can be varied by 30 cm to 68 cm.

Thus, for titanium alloy springs with a thickness of 1.3 cm, spring rates can be varied from 175 kN/m to 1750 kN/m. Different materials and thicknesses of springs are used to achieve different ranges of stiffness. The achievable spring rates of the 1-DOF simulator are listed in table 1. Also listed in this table is the maximum weight that can be supported by each set of leaf springs and the maximum round impulse so that the fatigue limit of the leaf springs is not exceeded.

To assure accuracy, a static calibration is performed on each set of leaf springs with its associated mounting table. For very high spring rates (greater than 875 kN/m), it is difficult to remove the effects of the mounting table stiffness. The equivalent stiffness of the simulator is then given by

$$1/K = 1/K_{springs} + 1/K_{table} \tag{2}$$

The equivalent stiffness of the simulator is then reduced from the leaf-spring setting. For a spring setting of 9,000 kN/m and a table spring rate of 35,000 kN/m the equivalent spring rate of the system is 7,200 kN/m.

Table 1. Characteristics of 1-DOF simulator

	Spring thickness (cm)			
	0.65	1.3	2.5	3.5
Spring rate $\left(\frac{kN}{M}\right)$				
Maximum	175	1,750	11,400	24,500
Minimum	35	175	1,750	8,800
Maximum weight on firing table (kg)	45	110	160	200
Maximum impulse* (N-s)	22	110	310	670

*Dependent on rate of fire and number of rounds fired; a function of fatigue limit.

A hydraulic damper is available to vary the damping coefficient of the simulator. Fluid flows between two hydraulic pistons through an annular space between a damping ratio pin and a cylindrical sleeve. The damping ratio, a function of the length of the pin inserted into the cylindrical sleeve, can be varied from 0.05 to greater than 1.0. The actual damping ratio is measured by a self-calibration feature of the 1-DOF simulator.

The gun mounted on the 1-DOF simulator may be represented as a second order spring-mass-damper system given by

$$m\ddot{x} + c\dot{x} + kx = F(t) \tag{3}$$

The resonant frequency of this system is given by

$$f = 1/2\pi\sqrt{k/m} \tag{4}$$

If the resonant frequency of the weapon mount approaches the firing rate of the weapon, malfunctions in weapon operation may begin to occur, particularly in self-powered weapons. A typical study of such weapon-mount interactions was performed on the 7.62-mm machine gun M240E1. This weapon, mounted on the 1-DOF simulator, is shown in figure 1, while the variation in firing rate as a function of spring rate is shown in figure 3. A distinct decrease in firing rate is apparent at a spring rate of 700 kN/m. The displacement of the mounting table at a spring rate of 260 kN/m is shown in figure 4, which also shows that mount displacement continues to increase as long as firing continues.*

The 1-DOF simulator is also capable of testing automatic cannons, both self-powered and externally powered. The 20-mm automatic cannon M197 is shown mounted

*This testing was used in the design of the mount for the production weapon.

on the 1-DOF simulator in figure 5. This weapon will continue to fire under all mount conditions, since it is externally powered; however, the forces transmitted to its mount and the weapon dispersion can vary considerably as a function of mounting conditions.

SIX-DEGREE-OF-FREEDOM SIMULATOR

The 6-DOF simulator, developed to suspend helicopter fuselages or turrets from armored personnel carriers, supplies a spectrum of vibrations to these mounted systems. Firing tests can be conducted from the suspended systems to study interactions caused by the shock and blast of the firing weapon. The fuselage of an AH-1G Cobra helicopter mounted on the 6-DOF simulator is shown in figure 6. The fuselage is suspended through the lift link which is normally attached to the helicopter rotor. The simulator platform is controlled to respond to firing impulses as the helicopter would in flight.

The simulator consists of a fork structure attached to a large tower. A gimbal system allowing controlled pitch and yaw motion is mounted between trunnions attached to the fork structure. Six actuators are connected between the gimbal system and a mounting platform. The helicopter is attached to the mounting hardware terminating at the lift link.

The six actuators are hydraulically controlled by a unique adaptive control system that allows the spring rate and damping of the mounting platform to be controlled in six-degrees-of-freedom. This allows the motion of the weapon platform during firing to duplicate the motion that would be encountered in the field.

The spring rate and damping of each actuator is individually controlled; however, a digital computer program is available to determine individual actuator settings to provide a desired 6-DOF spring rate and damping setting. These settings are manually set via the 6-DOF simulator control console shown in figure 7. The General Data NOVA 2 Computer, with 16K memory, which is used to perform all necessary calculations for the setup of the simulator is also shown in figure 7. A digital tape cassette unit is used for program and data storage.

Physical characteristics of the 6-DOF simulator are listed in table 2. The 6-DOF simulator can suspend weights up to 8,000 kg, including the mounting adaptors which attach a vehicle to the simulator. The simulator may be pitched down 10° and up 45° and yawed 70° either right or left. The Cobra fuselage can be pitched up only 26° and yawed 35° because of the limitations of range size. The Cobra is shown pitched up 20° in figure 8.

In addition to controlling the simulator response through the spring rate and damping setting, vertical accelerations and pitch and yaw motions are supplied to systems attached to the simulator. The magnitude of these motions is determined by the mass and inertia of the mounted system. The sinusoidal yaw motion limits for the Cobra fuselage attached to the simulator are shown in figure 9. This capability allows weapon control systems, including stabilization systems, to be tested under simulated target tracking conditions.

Table 2. Characteristics of 6-DOF simulator

Weights	
Tower	
Structure	23 ton
Sand	54 ton
Fork structure	16 ton
Gimbal	14 ton
Maximum suspended weight	8200 kg
Distance from floor to mounting surface	2.5 mm
Motion with AH-1G mounted	
Pitch	10° down
	26° up
Yaw	35° left
	35° right
Firing range	7.6 m wide
	6.7 m high
	25 m long
Impact area	sand butt
Projectile size limit	30-mm TP round
	40-mm TP grenade

An adaptor to suspend cupolas or combat vehicle turrets is also available. An artist's concept of this adaptor with a mounted cupola is shown in figure 10. This adaptor contains an additional hydraulic actuator to provide and control the pitch motion of mounted turrets. Turrets may be pitched up or down 15° with this actuator.

The simulator is also used to test selected portions of a weapon system mounted to the 6-DOF simulator. The 20-mm automatic cannon M35 mounted on a Cobra helicopter wing stub is attached to the simulator in figure 11. In addition, weapons can be mounted directly to the simulator to test operation in a vibration environment. The simulator is capable of providing vertical accelerations of 0.5 g to the mounted systems at frequencies up to 20 Hz.

The versatility of the 6-DOF simulator proves that the concept of simulation technology is feasible as a substitute for a significant portion of field testing at substantially reduced costs.

DATA ACQUISITION AND REDUCTION SYSTEM

To assure the validity of simulations and to measure weapon characteristics, a sophisticated data acquisition and reduction system has been developed by the Ware Simulation Section. A block diagram of system interconnections is shown in figure 12.

Transducers measuring weapon system parameters are connected to a junction box located on the wall of the firing range. This junction box is hard-wired by underground shielded cables to signal conditioning equipment located in the data acquisition room. This conditioned data is then recorded on an analog tape recorder so permanent records of all test results are available. An electronic calibrator, which can be operated either manually or under computer control, is available to input accurate electronic signals into the network so that procedural gains are quickly set up and to assure proper operation of the system.

Test data is also input to a Honeywell DDP-516 digital computer through a 16 channel analog-to-digital converter. This data is stored on a random access moving-head disc during test firings. Upon completion of a test, the data is sorted, converted to engineering units, and plotted on a graphics terminal. Thus, test personnel are provided with hard copies of test data within two minutes of the completion of a test.

In addition, if test data falls outside of predetermined limits, various types of data analysis routines are available for more complete study of the data. These techniques include time expansion of data, integration and differentiation of parameters, spectral analysis of parameters, and mechanical impedance data analysis.

CONCLUSIONS

The combination of the simulators and the data system available in the Ware Simulation Section provide a unique and modern method of obtaining information on weapon functioning and system interactions at a cost considerably below that for field testing. Also, the simulation techniques developed provide a more complete test of weapon systems than the standard, hard stand, go-no-go methods at no increase in cost. These techniques have been used successfully with a number of weapon systems to identify problem areas before full production. Simulation techniques can be confidently applied to acceptance testing of more complex systems, including turret stabilization components.

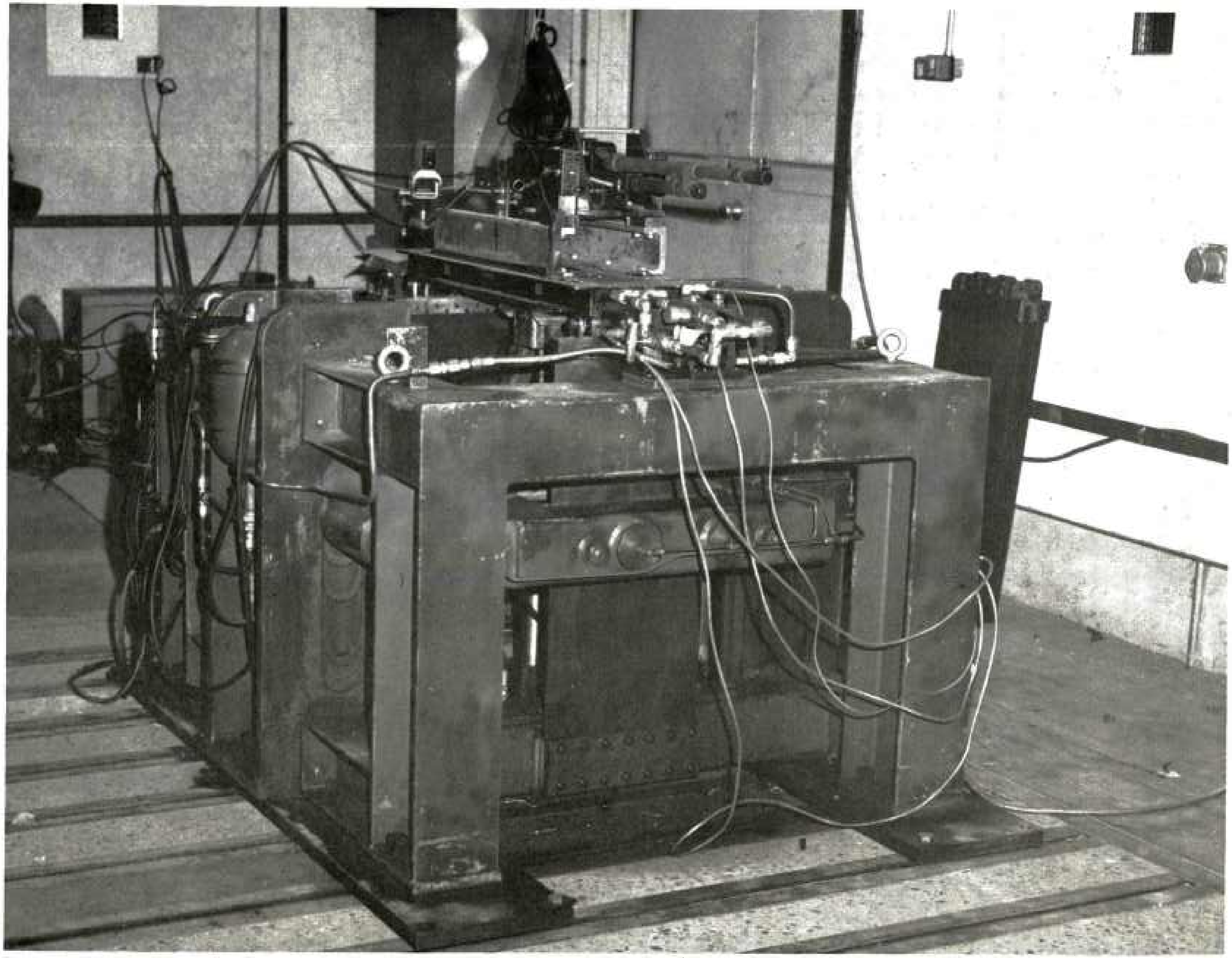

Figure 1. M240 machine gun mounted on 1-DOF simulator

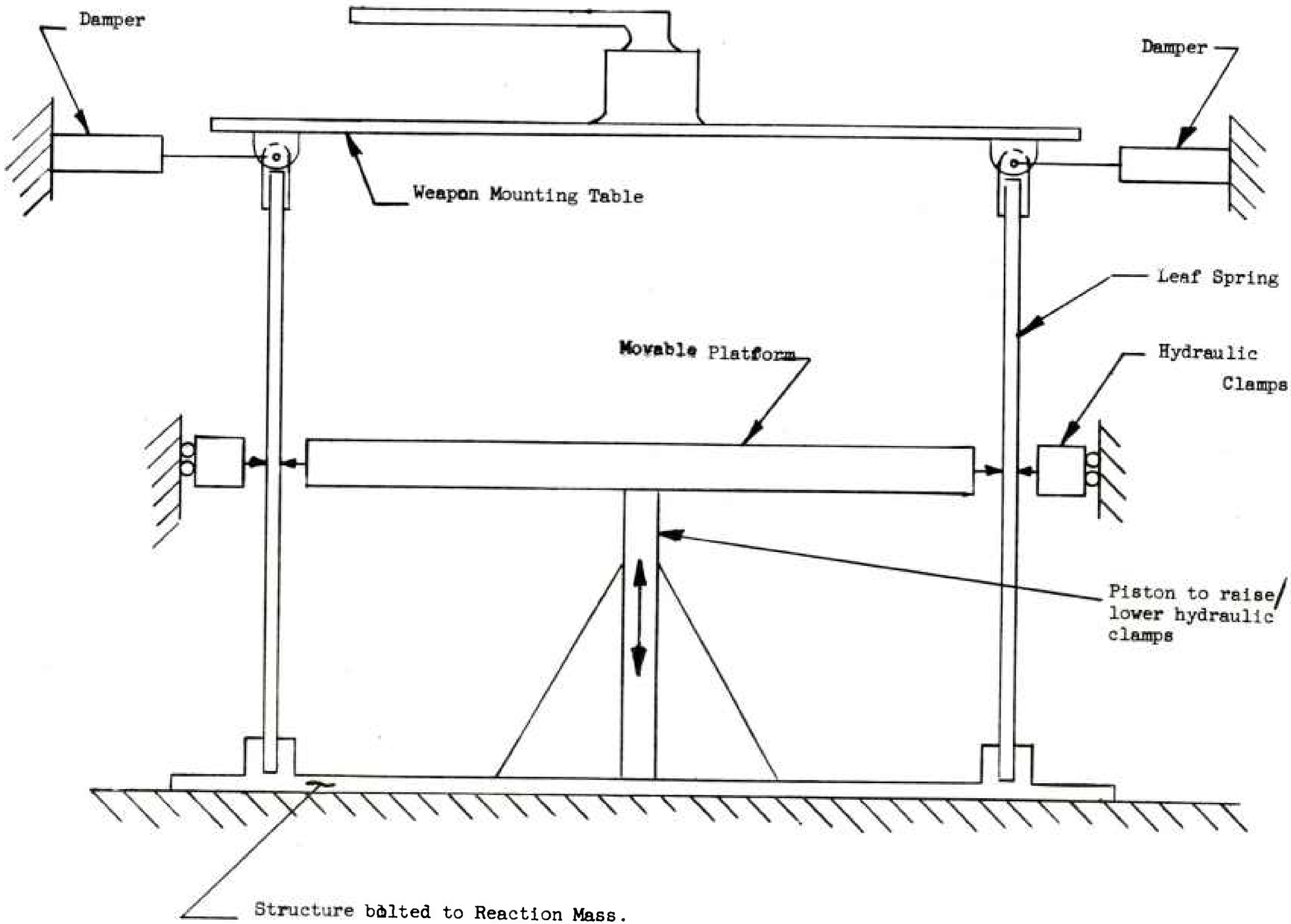

Figure 2. 1-DOF simulator

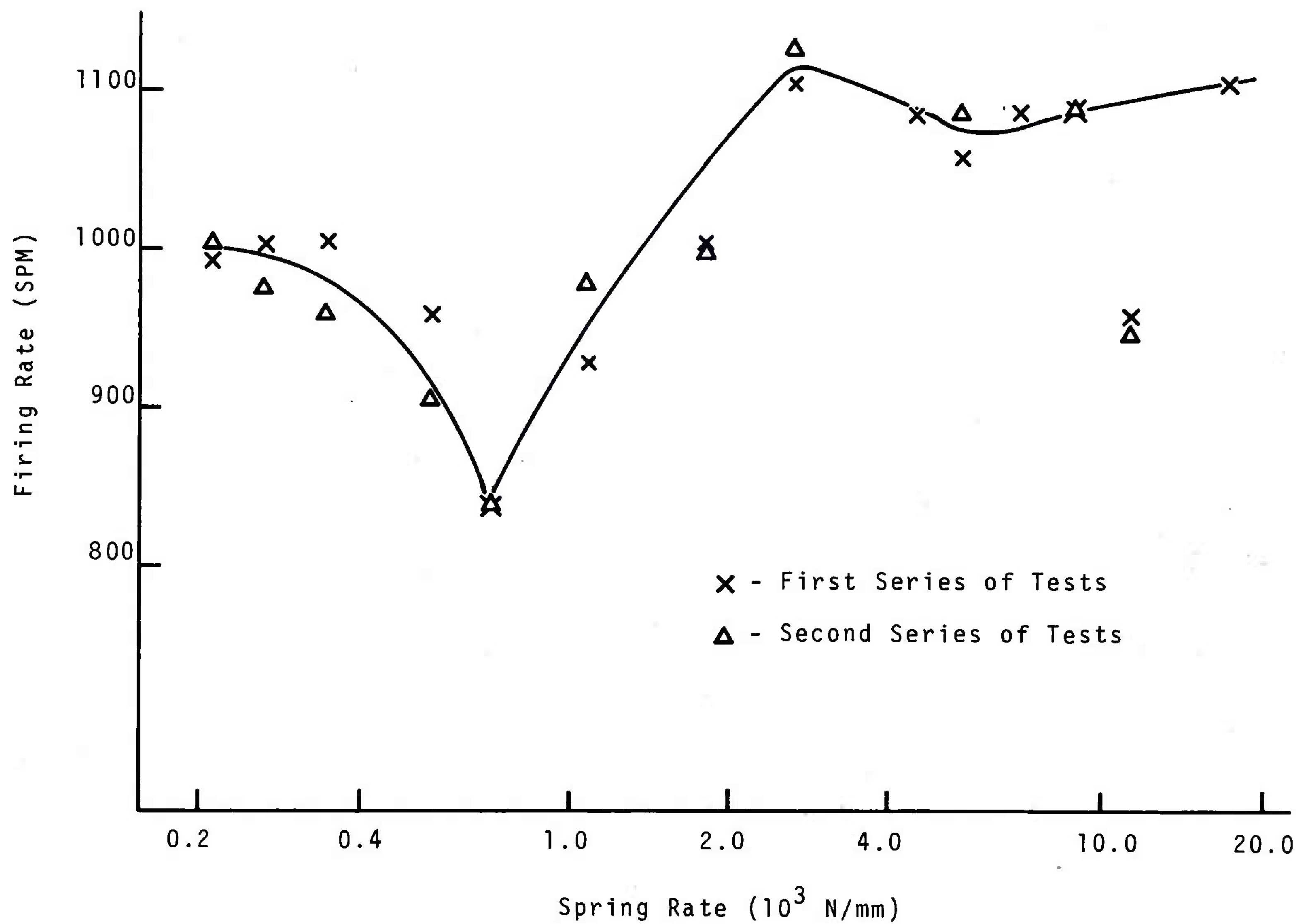

Figure 3. Firing rate vs spring rate for M240 machine gun

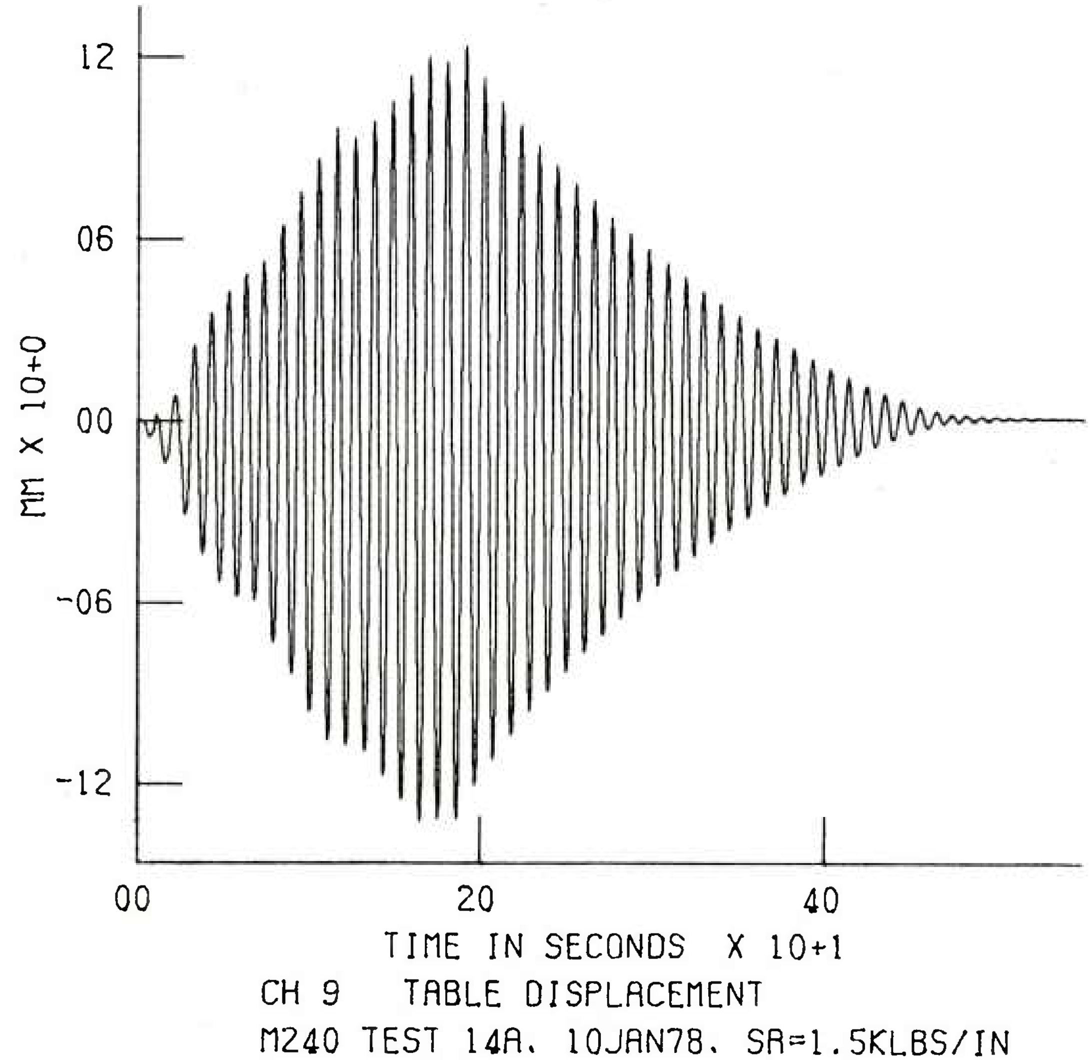

Figure 4. Table displacement during firing for M240

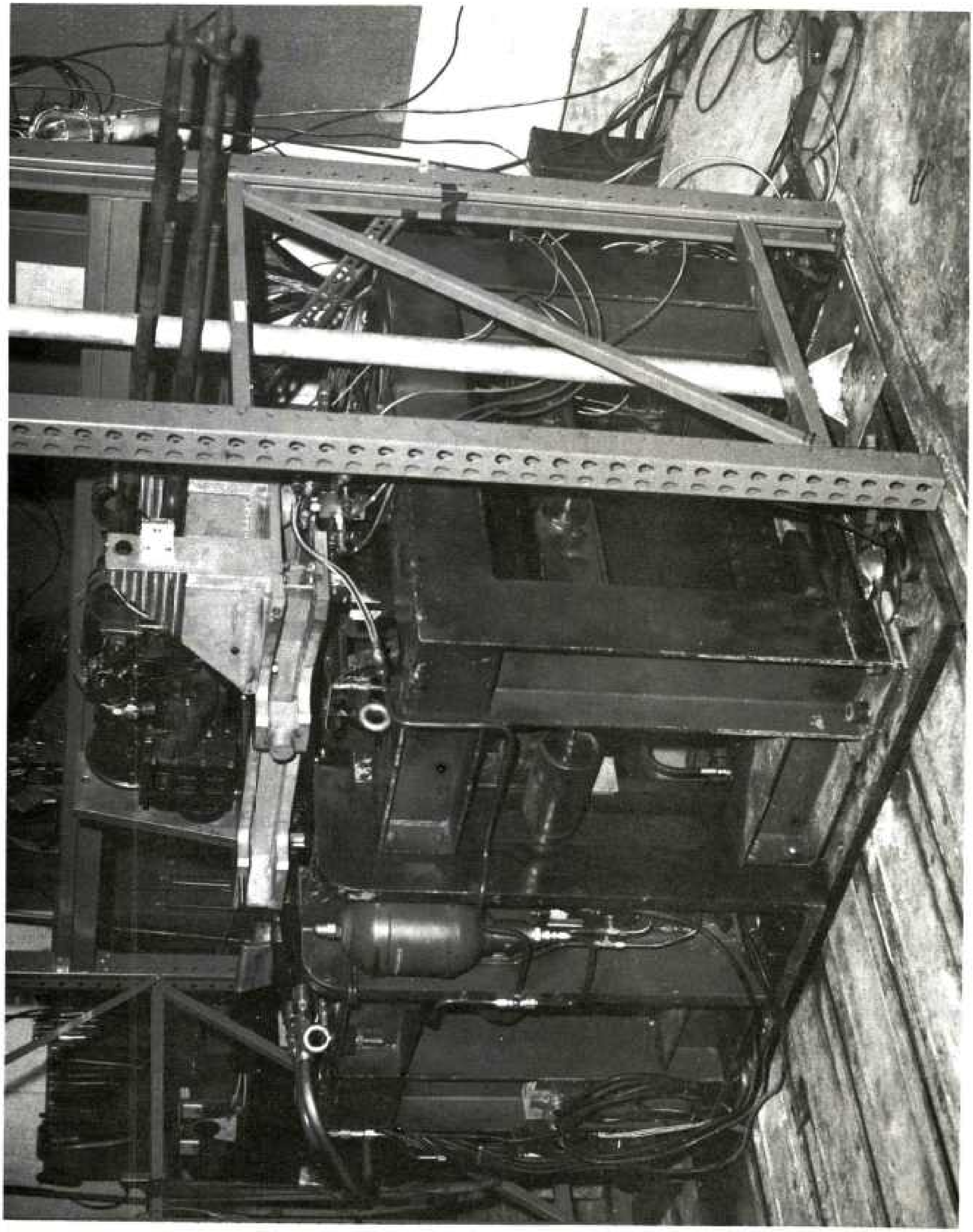

Figure 5. 20-mm automatic gun M197, mounted on 1-DOF simulator

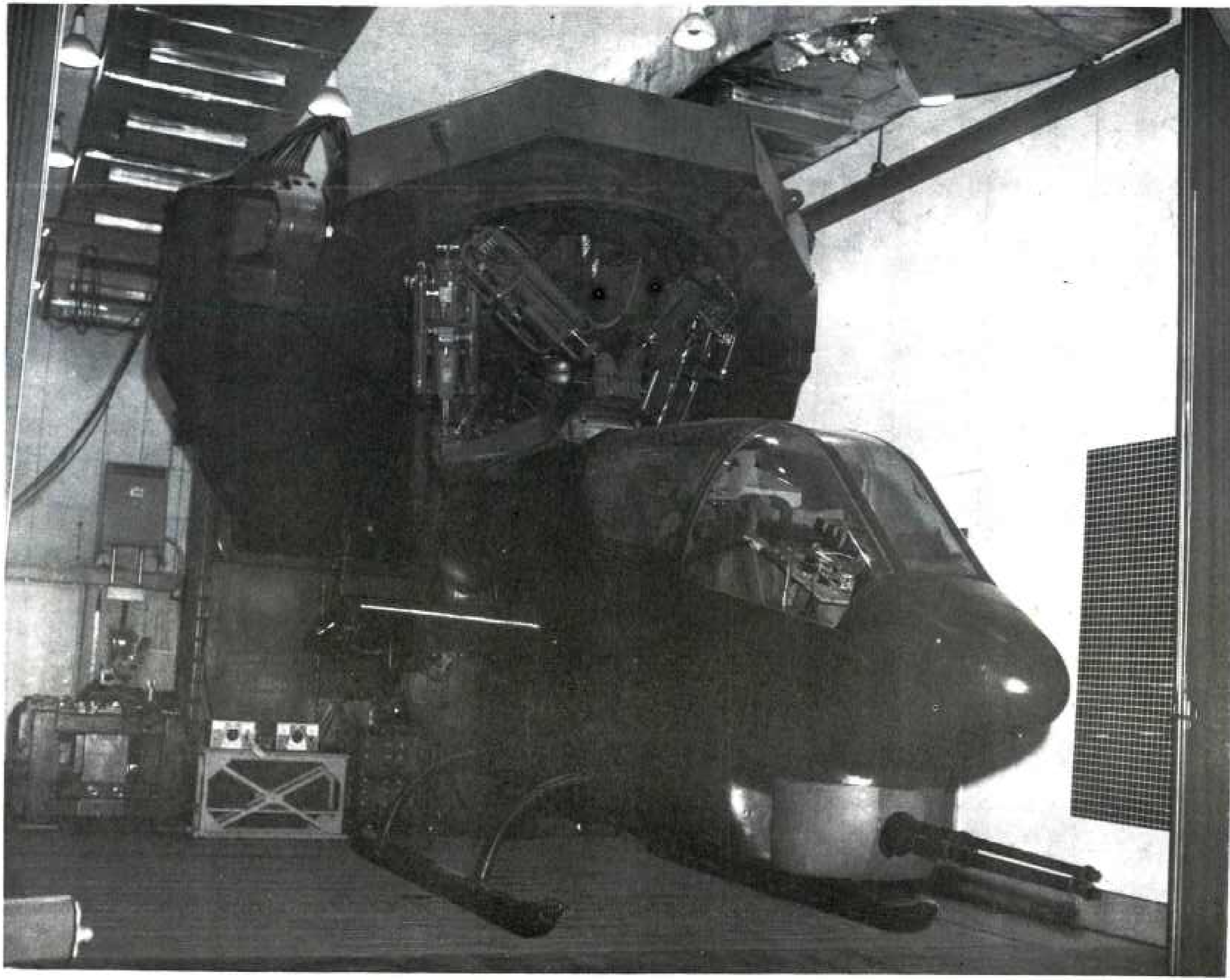

Figure 6. AH-1G COBRA fuselage mounted on 6-DOF simulator

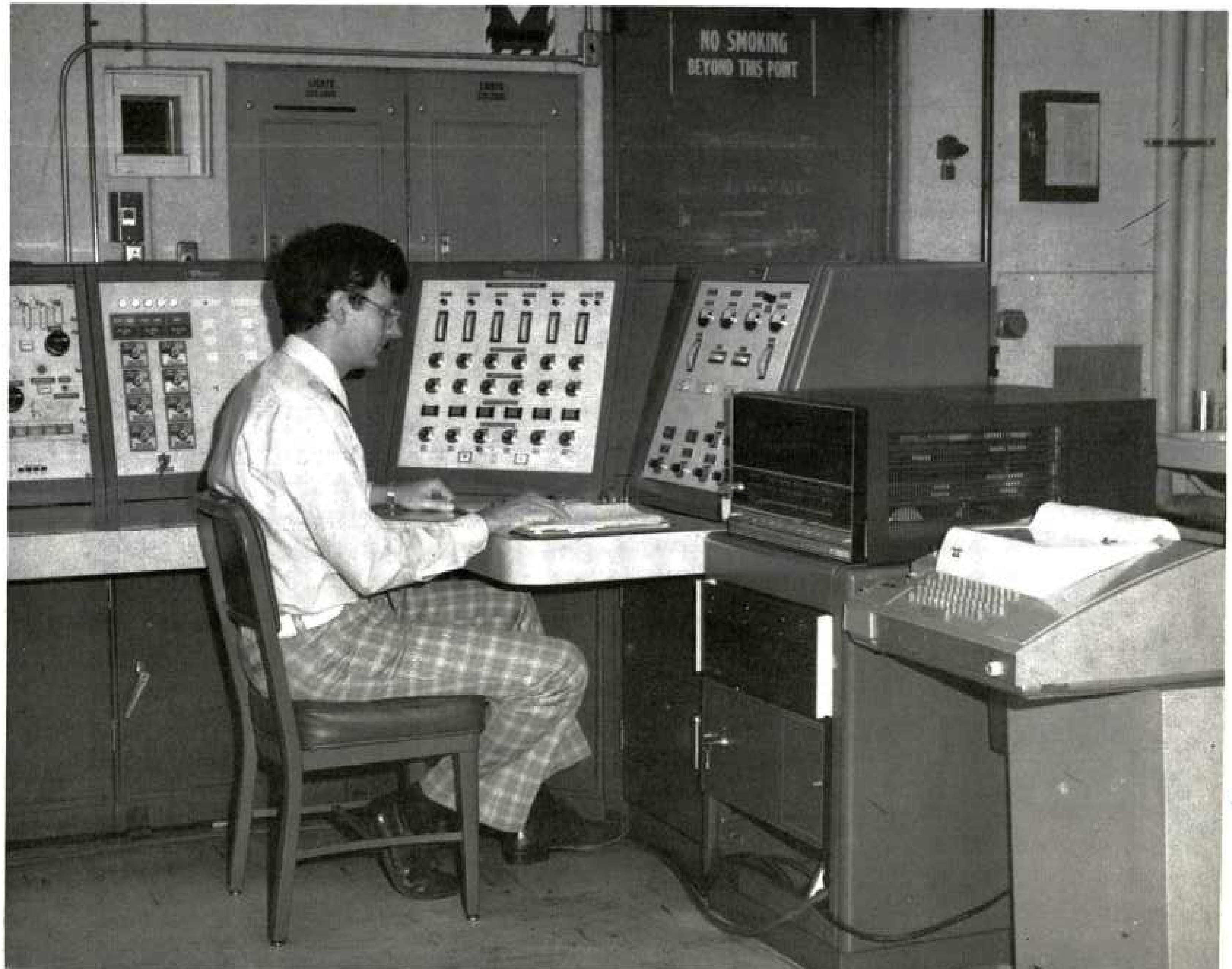

Figure 7. Control console for 6-DOF simulator

Figure 8. AH-1G COBRA fuselage pitched up 20°

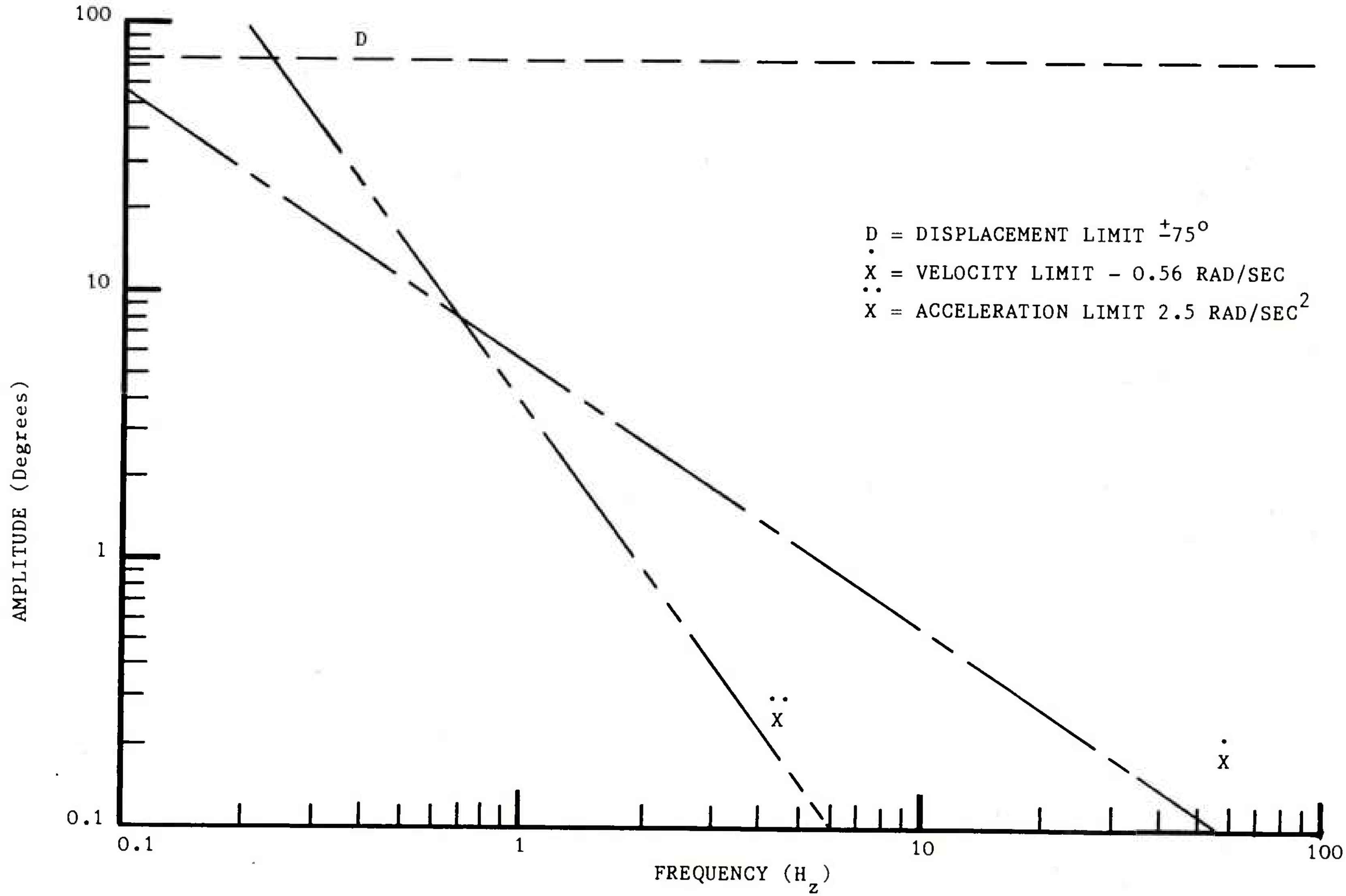

Figure 9. Yaw operating limits for AH-1G aircraft

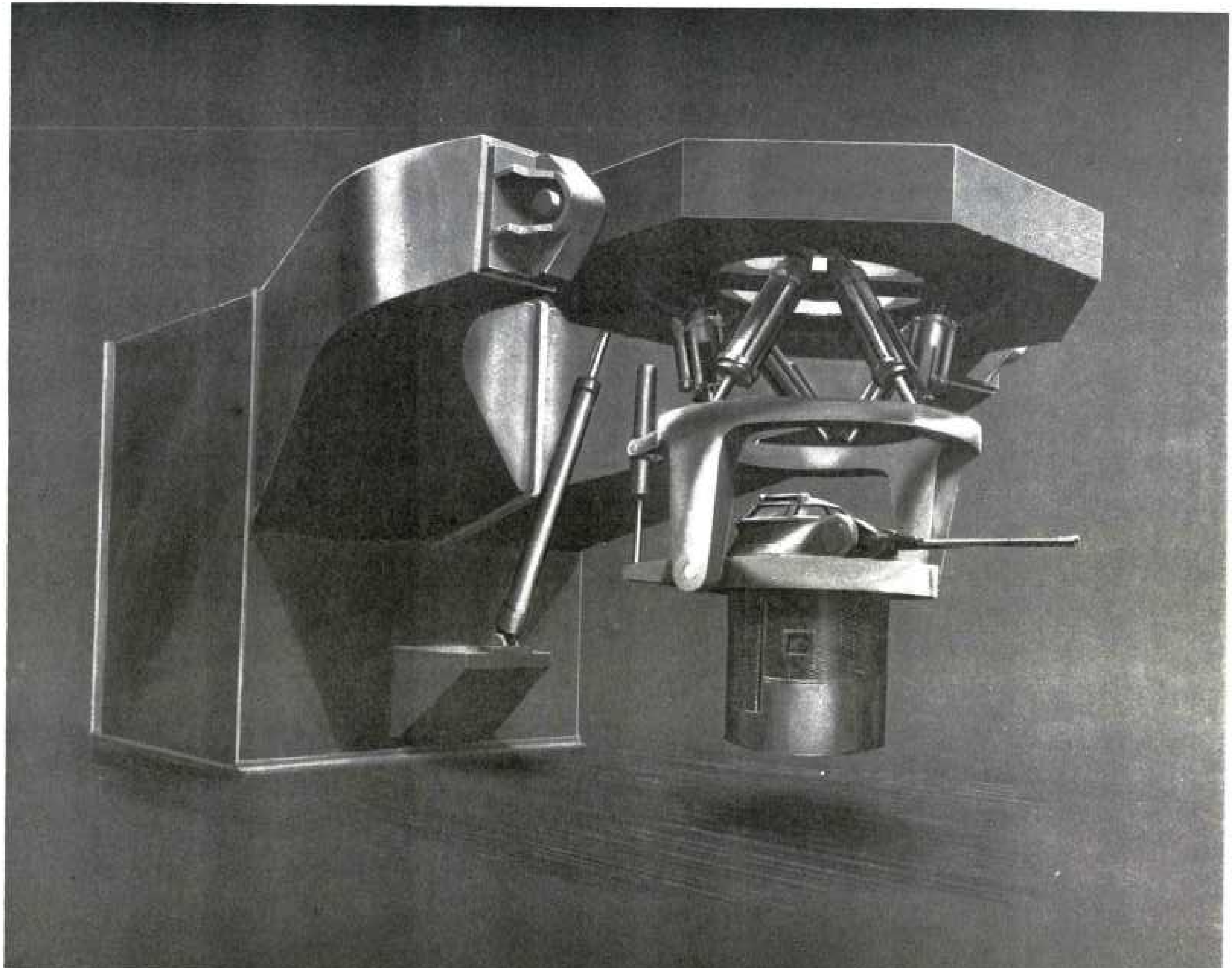

Figure 10. Turret adapter for 6-DOF simulator

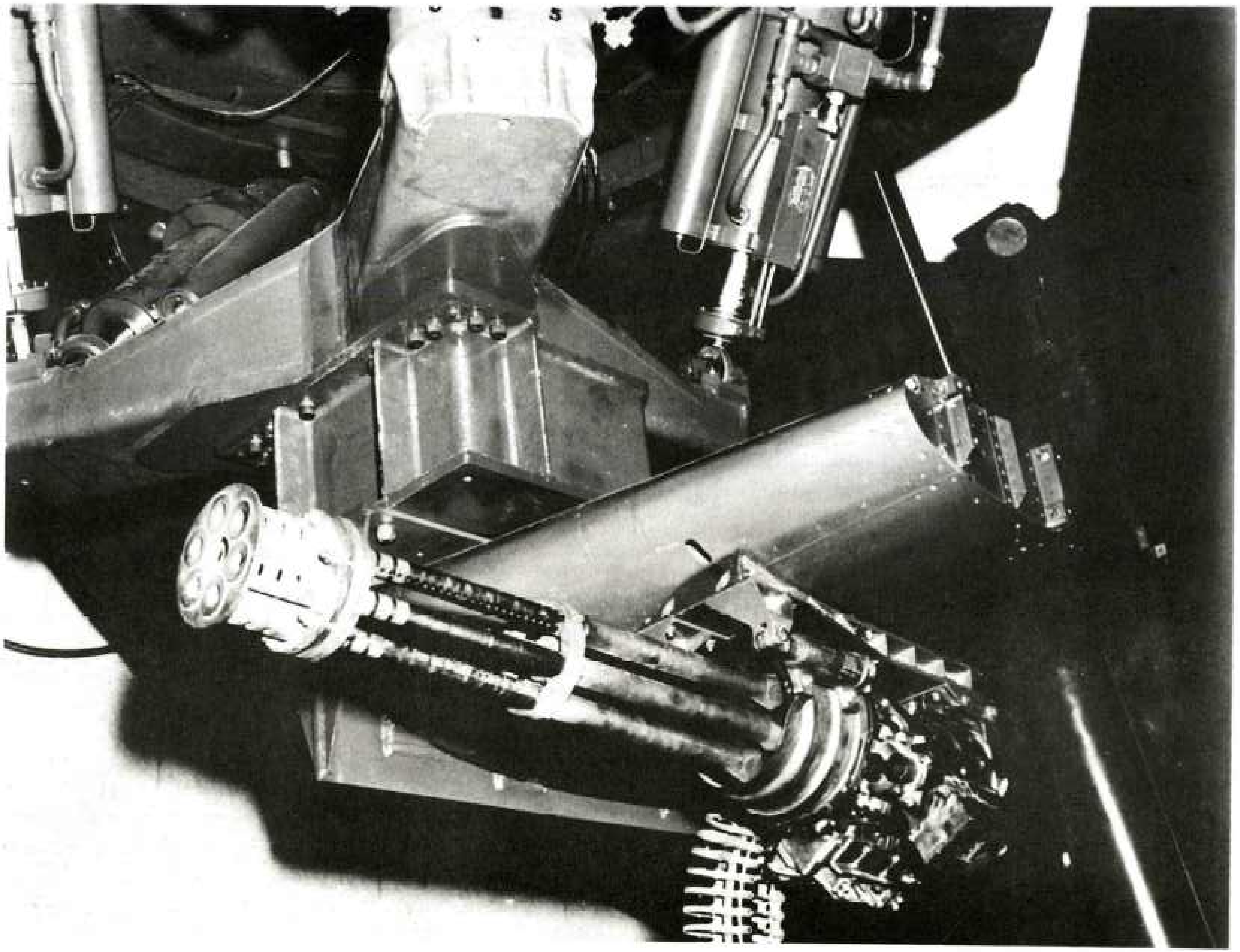

Figure 11. 20-mm automatic gun M35 mounted on 6-DOF simulator

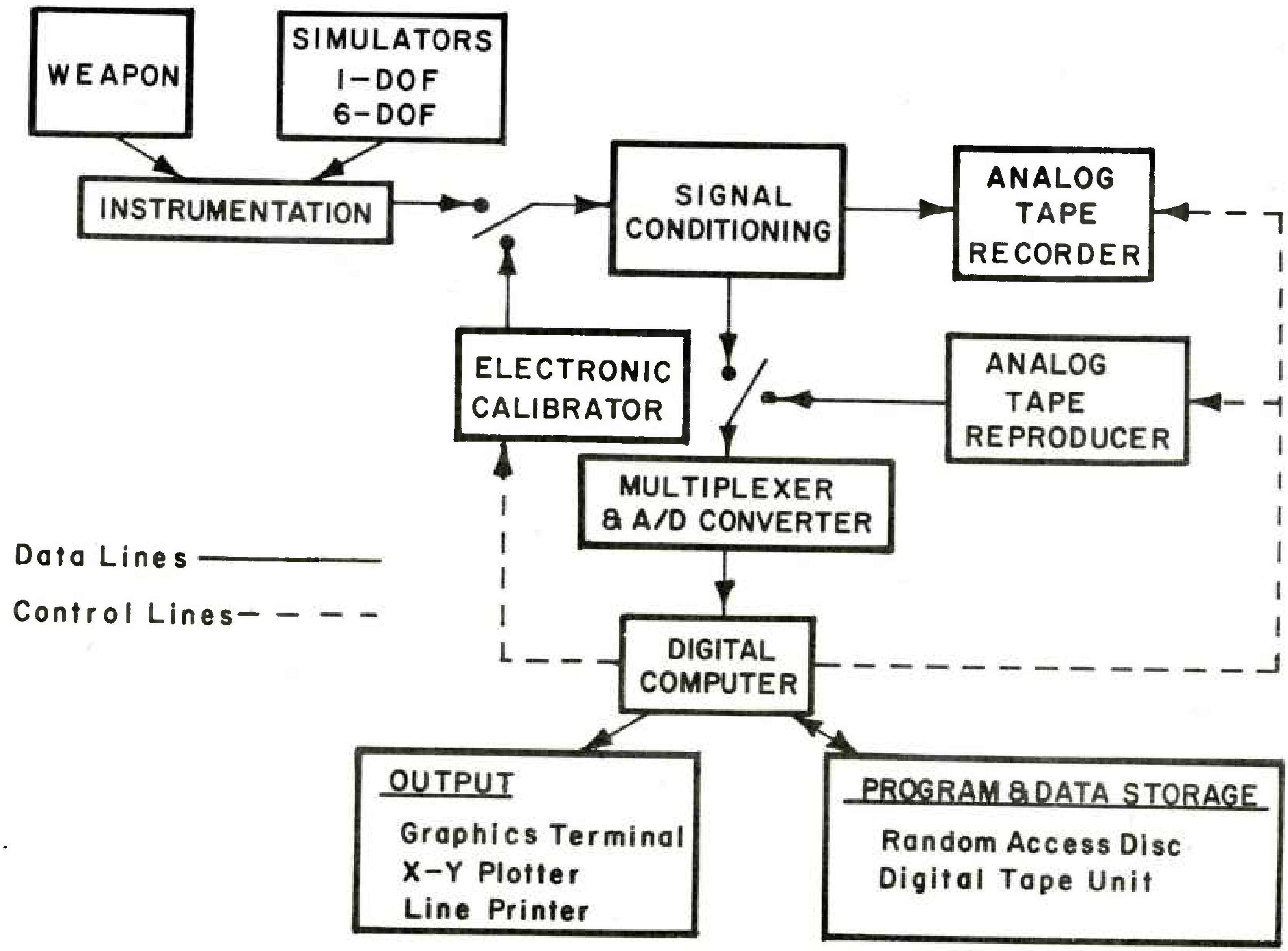

Figure 12. Data acquisition and reduction system

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